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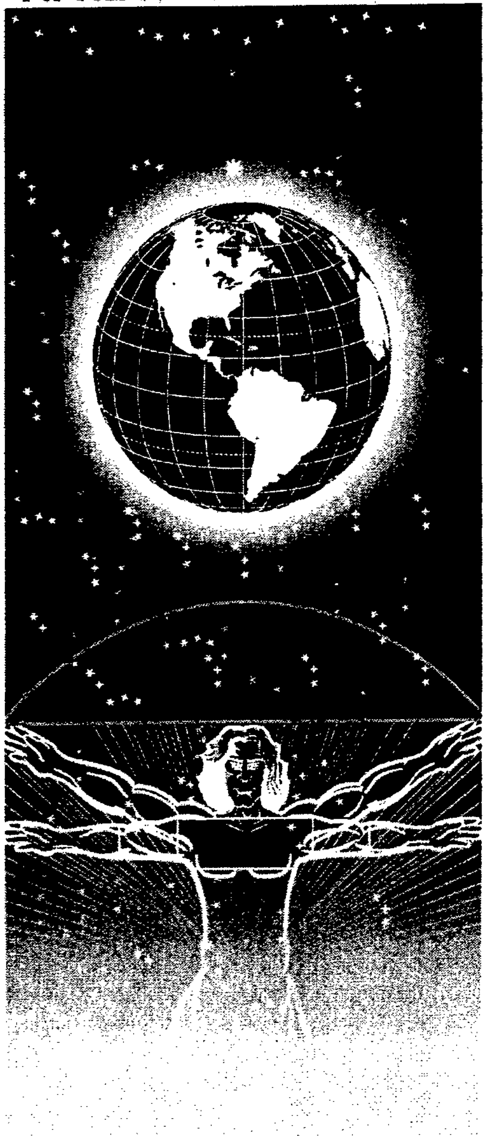

UNITED STATES AIR FORCE RESEARCH LABORATORY

COMPARISON OF HANDS-FREE VERSUS CONVENTIONAL WEARABLE COMPUTER CONTROL FOR MAINTENANCE APPLICATIONS

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FOR THE COMMANDER

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Past research on wearable computers for maintenance applications has focused on developing displays and presentation formats. This study emphasized wearable computer control technologies. Alternative control technologies were compared with standard and voice controls. Twelve subjects performed a synthetic maintenance task using three control device combinations for three different types of input. Time and error data were collected. The results show that for pointer movement, standard controls took significantly longer than voice. For discrete input, standard controls required significantly more time than voice and alternative controls. However, there were no significant time differences among controllers for text entry fill-in. Error results showed no significant differences. This research suggests that alternative and voice controls provide similar performance levels and both are superior to standard controls. In environments with changing noise spectra and noise levels such as a flight line, the alternative control suite provides hands-free control that complements voice without sacrificing performance.

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Comparison of Hands-free versus Conventional Wearable Computer Control for Maintenance Applications

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Past research on wearable computers for maintenance applications has focused on developing displays and presentation formats. This study emphasized wearable computer *control* technologies. Alternative control technologies were compared with standard and voice controls. Twelve subjects performed a synthetic maintenance task using three control device combinations for three different types of input. Time and error data were collected. The results show that for pointer movement, standard controls took significantly longer than voice. For discrete input, standard controls required significantly more time than voice and alternative controls. However, there were no significant time differences among controllers for text entry fill-in. Error results showed no significant differences. This research suggests that alternative and voice controls provide similar performance levels and both are superior to standard controls. In environments with changing noise spectra and noise levels such as a flight line, the alternative control suite provides hands-free control that complements voice without sacrificing performance.

INTRODUCTION

The development of wearable computer systems for maintenance applications promises to improve technician performance and reduce aircraft downtime by readily providing the required repair/modification information wherever the technician may be. However, many maintenance activities require the use of both of the technician's hands, therefore, conventional wearable input devices are inadequate for computer control. For example, if both hands are required to perform a wire continuity check, it is difficult to enter the obtained value via a wrist-worn keyboard.

While voice recognition systems offer hands-free control, they can be problematic in environments with changing noise spectra and noise levels (Chapman & Simmons, 1995). In these environments, alternative hands-free controllers are required that are resilient to the specific constraints associated with the maintenance technician's work environment.

The Air Force Research Laboratory Alternative Control Technology program (AFRL/HECP) is developing several hands-free devices for computer control. The devices utilize signals derived from the brain, muscles, voice, lips, head position, eye position, and facial gestures (Calhoun & Janson, 1991; Jennings & Ruck, 1995; Junker, Berg, Schneider & McMillan, 1995; McMillan, Eggleston & Anderson, 1997; Nasman, Calhoun & McMillan, 1997). These computer controllers can *replace* conventional systems or they can be used as a *supplement* to standard manual input devices or voice controls. In this manner, the combined potential of conventional and evolving alternative controls can be exploited to provide maintainers with a variety of new channels for controlling electronic devices. For instance, keypad control may be more efficient for filling out forms while a hands-free controller would be more appropriate for sequencing through procedures during manually intensive wire continuity tests.

To date the primary focus of research and development on wearable computers by the Air Force Research Laboratory Logistics Readiness Branch (AFRL/HESR) has been on display development and presentation formats (Friend & Grinstead, 1992; Kancler & Quill, 1997; Masquelier, 1991; Revels, Quill, Kancler & Masquelier, 1998; Webb, 1997). However, to fully exploit the potential advantages of the wearable computer as a maintenance aiding system, research and development must integrate hands-free control technology.

Under normal circumstances, the user must be able to provide several types of input to the wearable system. In the two dimensional, MS Windows operating environment, there

are three primary types of input: (1) pointer movement – the positioning of the cursor on the screen (commonly performed by moving a mouse), (2) discrete input – the selection of an object of focus (e.g., the left mouse button click), and (3) text entry fill-in (e.g., standard keyboard entry).

The current study compared three control suites: a standard control suite, a voice-only control suite, and an alternative control suite. Performance was measured for three types of control inputs (pointer movement, discrete, and fill-in) in a synthetic maintenance task environment.

METHOD

Participants

Twelve male maintenance and engineering specialists from the Air Force Research Laboratory served as subjects. Each subject was required to have corrected 20/20 vision. All subjects were under the age of forty.

Apparatus

A monocular head-mounted Kopin display (HMD) was used to display the presentation software in all conditions. The display was black on white monochrome with VGA resolution (640 x 480 pixels) and subtended approximately 30° of visual angle.

Three control device suites were used. The *standard* control device suite integrated a thumbelina miniature track ball and a wrist-worn keyboard. The *voice-only* control suite used the Verbex Voice Systems Rev 4.0 with a head worn microphone. Finally, the *alternative* control suite incorporated a head-mounted Gyropoint Pro II inertial mouse (for head-based cursor movement), the CyberLink electromyographic controller (for discrete control using facial gestures), and the Verbex Voice Systems Rev 4.0 for text entry.

Procedure

The task was a hands-busy maintenance cannon plug check. For this task, subjects used their control suites to manipulate between screens on the computer display while using a multimeter to measure resistance values between a given set of pins in the cannon plug.

Each session began with calibration of the CyberLink and speaker-dependent Verbex systems. This was followed by control device training for each suite of controls, which served to familiarize subjects with both the control suites and the HMD. Finally, each subject was trained on the cannon plug task using the control devices and the presentation software. During training, a single, rectangular cannon plug assembly was used. For testing, four circular cannon plugs were used; each plug contained either 12, 13, 55, or 79 "female" (recessed) pins.

The subjects performed sixteen trials (four trials for each of the four plugs) for each of the three control device suites for a total of 48 trials. Within each trial the subject performed all three of the input types (pointer movement, discrete, and fill-in). A typical trial was as follows:

To start, the subject used the first screen to determine which cannon plug needed to be tested (the appropriate plug was marked by a small gray button; see Figure 1). The subject then grasped the correct plug. Next, the subject needed to change to the subsequent screen via pointer movement. This entailed moving the pointer cursor from the center of the display to within the border of the gray button. No discrete input was required. For the standard control suite, the thumbelina trackball was used. For the alternative control suite, the head tracker was used. For the voice-only condition, the subject had to say the number of the plug to be tested.

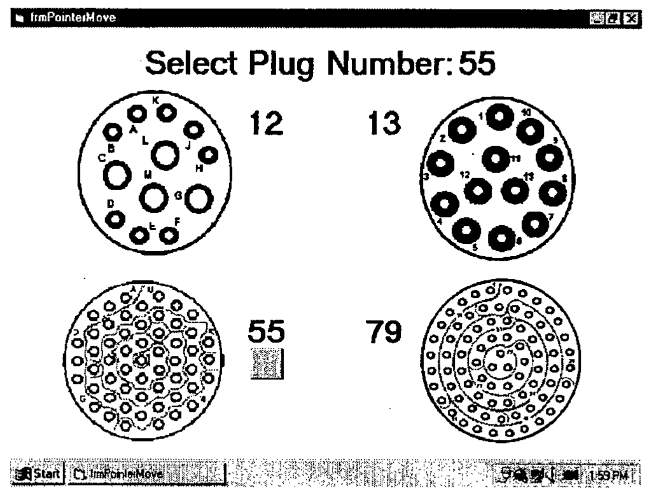

Figure 1. Example of a Pointer Movement screen

Next, the subject had to insert test adapters into the appropriate cannon plug pins (see Figure 2) and change to the last screen via a discrete input. For the standard controls, this

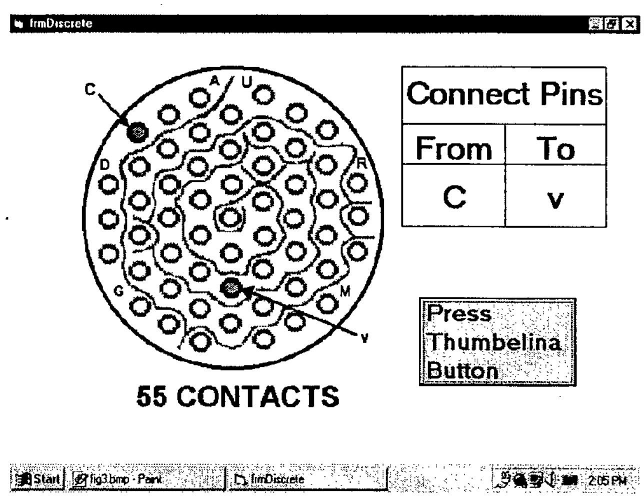

Figure 2. Example of Discrete input screen.

entailed clicking the left button on the thumbelina. For the alternative control suite, discrete input was performed by a facial gesture (such as a short jaw clench or eyebrow lift) that was relayed to the system using the CyberLink. For the voice-only condition, the subject said, "OK".

Finally, the multimeter was used to check the continuity of the circuit between the two pins and the value on the meter was entered on the fill-in screen (Figure 3) using either the keyboard (standard control suite) or voice (voice-only *and* alternative control suites). Four different resistance levels were used for the meter readings. If the subject did not enter the correct resistance value on the fill-in screen, an error was logged.

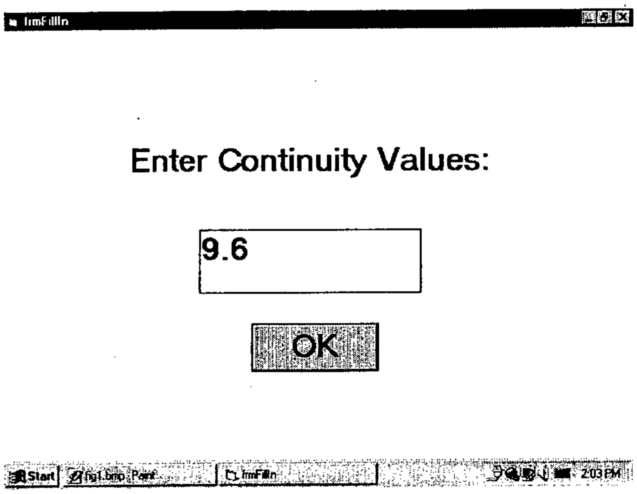

Figure 3. Example of a Fill-in screen.

Experimental Design

The study was a 3 x 3 within-subjects randomized block design. The independent variables were Control Device (Standard Control, Voice Control, Alternative Control) and Input Type (Pointer Movement, Discrete, Fill-in). Subjects received all possible combinations of control devices and input types.

Dependent variables were completion time and percent errors. Completion time was defined as the time elapsed from activation of the control device to next control device activation. Errors were defined as incorrect fill-in text entries. Throughout the study, the experimenter recorded observational information. Following the test, subjects completed a post-test questionnaire.

RESULTS

Data were analyzed using a repeated measures analysis of variance (ANOVA) procedure.

Task Time

Analysis of task time revealed significant main effects for Control Device [$F(2, 22)=32.58$, $p<.001$] and Input Type [$F(2, 22)=87.67$, $p<.001$]. The interaction of Control Device by Input Type was also significant [$F(4, 44)=12.63$, $p<.001$].

Figure 4 highlights the interaction effect using mean time in seconds. Using the Tukey test for paired comparisons, the results show no significant differences for pointer movement between head tracking (the alternative control suite) and either the thumbelina track ball (standard) or voice.

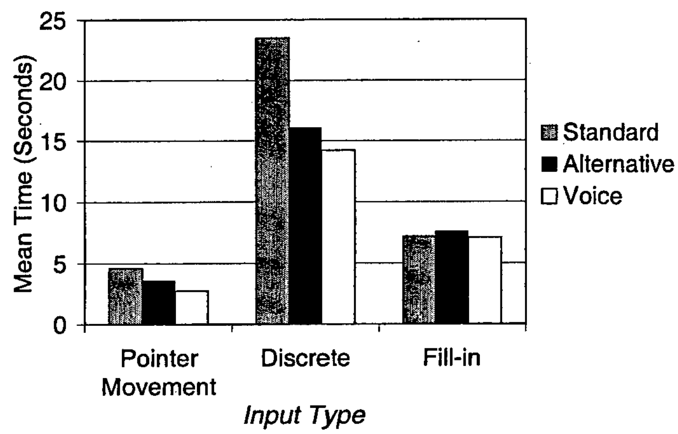

Figure 4. Interaction of Control Device by Input Type.

However, the standard thumbelina was significantly slower than voice. For discrete input, it took significantly longer to make a selection with the standard thumbelina than it did for either the voice or the CyberLink alternative controller. For text entry, there were no differences in text entry times for any of the control devices (voice or keyboard).

Percent Error

There were no significant differences in percent errors among the three control devices, however, the subjects did show large intersubject variability in the number of errors for the alternative control condition.

DISCUSSION

Task Time

The major result of this study was the interaction of Control Device by Input Type for time. Among controllers, performance differences for the different input types were related to the amount of hands-busy activity required by the task.

Only small differences were found for the pointer movement task – the small trackball used in the standard control suite took significantly longer than the voice control but was not significantly different from the head pointing control. During this portion of the maintenance task, only one hand was required for the task itself; therefore, the other hand was free to use the standard control.

In contrast, hands-on maintenance was most intensive during the screen requiring discrete input. While holding the cannon plug, the subject typically needed to find the appropriate pins on the plug, insert the test adapters using the thumb and forefinger, and then insert the multimeter leads into the ends of the test adapters. At this point a discrete input was required to advance the screen presentation. In the standard condition, subjects had to free up one hand and move it to the controller to activate it. Therefore, the standard control took significantly longer to activate than either the voice or hands-free alternative controllers.

For text entry fill-in, which was the least hands-busy of the conditions, there were no significant differences among the three types of controllers. However, a difference was expected because keyboard input (which was used in the standard control suite) tends to be slower than voice input (which was used by both the alternative and voice control suites) (McMillan, Eggleston, & Anderson, 1997). This lack of difference may be due to the fact that text entry was limited to short resistance readings taken from the multimeter with an acknowledgement (a typical entry was "7.9... OK") while McMillan et al. (1997) refer to tasks requiring more complex text entries in conjunction with other manual or visual tasks.

Percent Error

While differences in percent errors were not found for the three control device suites, there are some important issues to discuss. For three subjects in the alternative control condition, 25% of the entries contained an entry error. According to experimenter observation notes, the majority of these errors were due to inadvertent activation of the CyberLink discrete control. As the subject was performing the maintenance action of inserting the test adapters and taking the multimeter reading, occasionally a facial gesture (electromyographic signal) would accidentally activate the CyberLink causing the screen to advance. Because the screen showing the correct pin contacts would disappear, the subjects had trouble remembering which pins to measure. This increased the likelihood that the wrong pins were tested and erroneous readings were entered.

CONCLUSIONS AND RECOMMENDATIONS

The results of this research suggest that hands-free input devices are equal to or better than standard manual controls. For the discrete input task used in this experiment during a manually intensive step, both voice and the electromyographic (EMG) controls were better than the standard control. For the pointer movement task, the voice control was better than the standard control. However, the lack of significant differences between the standard and head-based control devices indicates that head-based control is a definite candidate pointer control when the noise environment precludes the use of voice recognizers. Head-based pointer movement may be even more advantageous for tasks in which the format is more complex such that pointer positioning cannot be readily made by voice commands.

In cases where there were no significant differences across input devices, the results suggest that the active control suite can be tailored to better tolerate some environmental constraint or, in the absence of constraints, to whatever device the operator prefers. For instance, according to the post-study questionnaire, subjects in the present study prefer a voice-only control suite when possible. However, for task environments with changing noise spectra and levels, there are non-speech hands-free control alternatives that provide comparable control.

Future Research

Further research in this area is in progress. An Air Force flight line maintenance field evaluation is planned whereby the alternative control suite can be used as a supplement to the voice and standard control suites. Subjective feedback to this combination of supplementary computer controls will be collected.

Furthermore, to reduce unintentional activation of the EMG control device, further study is underway on advanced feature detection algorithms to enable a purposeful EMG input to be more reliably discriminated from an inadvertent input.

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